Narrow Resonances in Effective Field Theory

Paulo F. Bedaque[1], H. W. Hammer[2] and U. van Kolck[3]
[1] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*
[2] *Helmholtz-Institut fur Strahlen- und Kernphysik, Universitat Bonn, 53115 Bonn, Germany*
[3] *Department of Physics, University of Arizona, Tucson, AZ 85721, USA*

Nucleons in light nuclei have typical momenta that are small compared with the typical QCD scale of 1 GeV. At these low momenta, QCD can be conveniently represented by a hadronic theory containing all possible interactions consistent with the QCD symmetries. It is crucial to formulate a power counting that justifies a systematic and controlled truncation of the Lagrangian according with the desired accuracy. Nuclei offer a non-trivial challenge because one wants such a perturbative expansion in addition to the non-perturbative treatment of certain leading operators, which is required by the existence of shallow bound states. By now, two-, three- and four-nucleon systems have been studied with EFT. While much is still to be understood, many successes have been achieved

The extension of EFTs to larger nuclei faces computational challenges, as do other approaches. As a first step in this extension we can specialize to very low energies where clusters of nucleons behave coherently. Even though we avoid many interesting issues of nuclear structure, we can still describe anomalously shallow (halo) nuclei and some reactions of astrophysical interest. Reactions involving more complex nuclei are frequently characterized by narrow resonances near threshold. One example, the $p_{3/2}$ resonance in neutron-alpha scattering. A good description of the data throughout the resonance region was found at the expense of the resummation of two operators in addition to the unitarity cut. Such a resummation requires *two* fine-tunings, which is somewhat surprising.

Here we generalize the analysis of shallow, narrow resonances in EFT. We discuss the power counting for resonances in any partial wave, and clarify the scope of unitarization. Using use n-α scattering as an example, we find that only one fine-tuning is necessary to describe the phenomenology, which reaffirms the hope that nuclear structure is not dominated by an ever increasing number of coincidences.

We have considered explicitly only the case of identical, spinless, heavy particles, but the same ideas apply to other cases, such as π-N scattering near the Δ resonance and various low-energy nuclear reactions. We illustrated this statement by a study of n-α scattering.

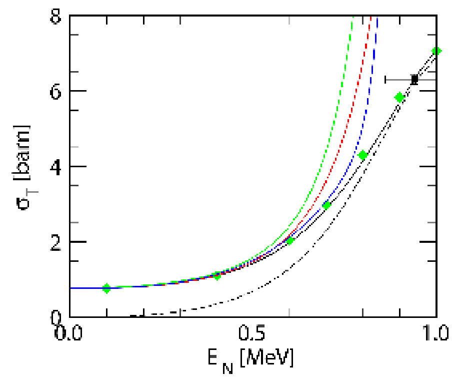

FIG. 1: The total cross section for n-α scattering(in barns) as a function of the neutron kinetic energy in the α rest frame (in MeV). The diamonds are evaluated data and the black squares are experimental data. The solid red, green, and blue lines show the result in the EFT without resummation at LO, NLO, and NNLO, respectively. The black dashed and solid lines show the result in the EFT with resummation at LO and NLO, respectively.

REFERENCES

[1] P. F. Bedaque, H.W.Hammer and U. van Kolck, *Phys.Lett.B* 569:159-167, (2003).